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Wade
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EFFECT OF ANNUAL GRASS FIRES ON ORGANIC MATTER AND OTHER CONSTITUENTS OF VIRGIN LONGLEAF PINE SOILS [1]

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INTRODUCTION

The winter burning of dead grass left unconsumed by grazing animals from the growth of the previous season is a world-wide practice of very ancient origin, particularly in humid regions where uncut grass does not cure into palatable winter forage. By the use of grass fires the Indians maintained open grazing lands for the bison and pronghorn antelope, the largest herds of grazing animals that the world has known. This practice of the Indians was considered beneficial to the land and was continued by white men, particularly in the humid longleaf pine region of the South, as a means of keeping down the underbrush and improving the pasturage for cattle. In the longleaf pine region a large part of the virgin soil is burned over each year. Hilgard (*10, p. 495*),[3] writing of the longleaf area of southern Mississippi, stated:

"The land * * * affords but indifferent pasturage, except the first season after burning-over; probably because of the effect of the minute amount of ashes so added."

Referring to the effect of grass fires on forest growth, Harper (*8, p. 668*) in 1913 stated:

> * * * they return immediately to the soil the mineral plant food stored up in the leaves. The amount of the available plant food in the soil of the pine forests is usually rather limited, and these frequent fires thus enable the pine to do business on a small amount of capital, as it were.

The literature does not seem to record any conflict with the empirical observations of the users of grass fires until recent years, when objections to the use of fires were made on the theoretical basis that the fires destroy organic matter and nitrogen to the detriment of soil fertility. The general unsupported argument against the use of fire was stated by Van Hise (*24, p. 238*) in 1910, as follows:

> The fires do not simply confine themselves to the timber, but they burn the humus in the soil itself. Frequently, after a great forest fire, and especially if the fires run over the same area two or three times, there is left of the soil, sand, and other minerals, but little of the original organic material.

Mattoon (*16, p. 48*) in 1931, states:

> The leaves, or "straw", from pines contain considerable nitrogen and small amounts of phosphoric acid and potash. A ton might contain these essential fertilizing elements to the value of $2 to $4. An unburned pine woods may have as much as 10 to 15 tons [per acre] of leaves and other organic matter.

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[2] The writer is indebted to H. R. Reed, formerly of the Bureau of Plant Industry, who spent considerable time in making the final legume counts. Acknowledgment is made also to W. F. Hand, State chemist of Mississippi, for analyses of soils and for determinations of the protein and ash content of grasses.

[3] Reference is made by number (italic) to Literature Cited, p. 821.

However, Mattoon gives no basis for his statements and does not indicate any way in which organic matter and nitrogen, on top of the virgin soil, might be recovered in the soil for the use of growing plants.

RELATED INVESTIGATIONS

Alway and Rost (*2*), from experimental work in 1918–19, found that burning did not influence the immediate fertility of the mineral soil and concluded that any loss in productivity would depend on the loss of nitrogen contained in the forest litter, since the mineral elements are returned immediately to the soil by fire. In later experiments Alway found that burning the forest floor as compared with plowing under the natural litter had no significant effect on crop production either immediately following (*1*) or over a series of years.[4]

Greene (7), in 1929, showed that cattle made 44.4 percent greater agins on burned native grass pastures than on similar unburned pastures over a period of 4 years.

The literature in regard to the accumulation of humus and nitrogen in cultivated soils and their effect on crop production is voluminous. Such literature, however, is concerned exclusively with the problem of green manuring, or the turning under of plant residues, and does not consider the problem of humus and nitrogen or their accumulation in soils that have not been plowed and are to be handled as virgin soils in forests or pastures where vegetation is either burned or left to decay where it accumulates on top of the soil.

The emphasis placed by popular agricultural literature on the value of organic matter plowed under, without regard to the quality or quantity of the material to be turned under, has, no doubt, created a tendency to overestimate the fertilizing value of vegetative growth on virgin soils. Moreover, the theoretical grounds on which deductions may be based are not always realized in practice. Such a concept for virgin soils leaves out of consideration the methods by which nature incorporates plant residues with the soil.

The importance of organic matter in the soil has always been recognized, but a sharp distinction must be drawn between organic matter in the soil and on top of the soil. According to Pieters (*19*), organic matter on top of virgin soils may be incorporated with the soil by the action of water or glaciers, by rodents, insects, earthworms, and micro-organisms, and by the sharp hoofs of grazing animals, but chiefly by the decay of plant roots.

Soil nitrogen in any form is derived originally from the gaseous nitrogen in the air and is a rather unstable and transient material, the gains and losses of which are perhaps not yet fully explained. Small quantities of gaseous nitrogen, in forms available to plants, are added to the soil by rainfall and by free-living micro-organisms, but the chief source of increase is through the action of the micro-organisms associated with legumes. Finnell and Houghton (*6*) found that 15.45 inches of rainfall in 1930 added 1.42 pounds of nitrogen per acre. No measure of the quantity of nitrogen per acre fixed by free-living organisms seems to have been obtained, and the effect of this class of organisms appears to be almost purely speculative.

[4] Unpublished information.

Nitrogen is an essential element of plant growth, and the nitrogen content of the soil is closely associated with the organic-matter content. Plants other than legumes, grown and left in place, do not add nitrogen to the soil but transform soil nitrogen into organic nitrogen with a loss to the soil in the process. Because of the known ability of legumes to store a considerable quantity of nitrogen extracted from the air, in both the root and aboveground portions of the plant, the maintenance or increase of nitrogen in virgin soils may depend largely on the character of the plant population.

In annual legumes one-fourth to one-third of the total nitrogen has been found by the Mississippi Agricultural Experiment Station to be in the portion of the plants below ground,[5] and in some perennial legumes nearly half of the nitrogen is in the underground portions (*19*, p. *74*).

Lyon and Bizzell (*15*), by lysimeter experiments, for a period of 15 years, in which the nitrogen added by rainfall and manure and removed by the crops and in the drainage water was carefully measured, found that in tanks containing growing legumes there was an increase of nitrogen in the soil equivalent to about 60 pounds per acre per year. When the tanks did not produce crops for 10 years and then grew nonlegumes for 5 years, the loss of nitrogen from the soil was at the rate of about 25 pounds per acre per year.

Sievers and Holtz (*21*) have shown that both the organic-matter and nitrogen increase in soils is influenced by the nitrogen-carbon ratio of the plants grown on the soil or turned under.

In the mature stages of plants it has been shown by LeClerc and Breazeale (*12*) and others that leaching of the mineral elements from plants in place occurs in considerable quantities, but that leaching of nitrogen is relatively unimportant.

Soil nitrogen is decreased by the removal of crops which contain nitrogen, by conversion into ammonia gas and gaseous nitrogen through the action of micro-organisms, both bacteria and fungi, and by leaching.

Heck, Musbach, and Whitson, as reported by Clark (*4*), found that the loss of organic nitrogen from manures on the ground in free circulation of air is much more rapid than below ground. The same relation between nitrogen in the aboveground and below-ground portions of mature plants would be indicated.

Nitrate nitrogen, the form most available as a plant nutrient, is readily soluble and is quickly leached away if not taken up by growing plants. Lyon and Bizzell (*14*) have shown that the loss of nitrogen by leaching was 17 times as much on uncropped land as on cropped land. Because of the loss of nitrogen both as ammonia and as nitrate on uncropped land, the use of winter cover crops as well as summer growing crops is generally advocated to conserve nitrogen on tilled soils in humid areas with mild winters. On virgin soils a constant maximum growth of herbage is indicated to conserve soil nitrogen.

The foregoing references underlie the concept derived from the experimental data to be presented. Although fire has, no doubt, been the most violent if not the most active chemical reaction present on the soil of the virgin longleaf pine region and is known to have a very active influence on the plant population of virgin soils, no data other

[5] Unpublished information.

than the limited work cited have been found showing the influence of frequent or annual burning on the fertility of the soil, as compared with protection from fire.

EXPERIMENTAL PROCEDURE

A tract of 320 acres of virgin land near McNeill, Miss., reproducing to longleaf pine about 20 years after the virgin timber had been removed, was fenced and divided into four experimental areas in 1923. Previously the land had been unfenced open range, subject to annual or periodic burning and lightly grazed by cattle. Since the fenced area was a part of a large area of open land with no natural barriers to fire or grazing, it is believed that the areas as divided had received uniform treatment before being fenced. This area is typical of the rolling longleaf pine hills of southern Mississippi. It has an elevation of 230 feet, and is well drained, as are the soils of the heavier type in longleaf pine areas.

Two areas of 150 acres each were grazed, one of which was burned annually during winter or early spring, beginning in 1923. Two 10-acre areas were not grazed, and one of these was burned annually. A detailed soil map of the area, made by the Bureau of Chemistry and Soils of the United States Department of Agriculture, was used as an aid in establishing the experimental areas and plots.

No soil analyses were made at the beginning of the experiment, since the studies undertaken concerned mostly problems of forage production. Soil analyses were made later in seeking an explanation of differences in forage growth under different treatments. Detailed studies of the variations in the plant population were made annually.

To determine the effect, on the soil, of burning the grass annually over a considerable period of time, analyses were made of soil samples collected on April 23, 1929, about 3 months after growth had begun in the spring and during the season of flush growth, and on January 10, 1930, during the dormant period. As it was recognized that individual samples might vary in chemical composition within a radius of a few feet, five random samples were taken to a depth of 6 inches for each soil type, and these five were mixed thoroughly to form a composite sample.[6] In addition to the principal studies relating to organic matter and nitrogen content of the soil, other tests dealt with density of plant growth, moisture content, and micro-organisms in soil from burned and unburned areas.

EXPERIMENTAL RESULTS

ORGANIC MATTER AND NITROGEN

Table 1 shows the content of organic matter and nitrogen from moisture-free samples of soil on the dates mentioned.

In samples taken in April the average organic-matter content of soil from the burned areas was 3.17 percent as compared with 2.59 percent for the unburned areas, or a ratio of about 1.2:1. The corresponding figures for nitrogen content were 0.047 and 0.055, or a ratio of about 0.9:1. Although the samples collected in April showed a variation in organic matter in favor of the burned areas in each instance, the proportion of nitrogen to organic matter was sometimes

[6] Soil samples were collected by the Southern Forest Experiment Station of the U. S. Forest Service. Soil analyses were made by W. F. Hand, State chemist of Mississippi.

TABLE 1.—*Organic matter*[1] *and nitrogen in composite samples of moisture-free soils taken Apr. 23, 1929, and Jan. 10, 1930, from soils subjected for 7 and 8 years, respectively, to the treatment indicated*

Soil type[2] (fine sandy loam)	Grazed area				Ungrazed area			
	Burned		Unburned		Burned		Unburned	
	Organic matter	Nitrogen	Organic matter	Nitrogen	Organic matter	Nitrogen	Organic matter	Nitrogen
APRIL 23, 1929, SAMPLES								
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Orangeburg	2.41	0.033	2.30	0.050	2.47	0.045	2.33	0.040
Norfolk	3.36	.046	2.62	.050	2.67	.050	(3)	(3)
Ruston	4.81	.053	2.40	.050	(3)	(3)	2.98	.050
Kalmia	3.29	.053	2.89	.090	(3)	(3)	(3)	(3)
Average	3.47	.046	2.55	.060	2.57	.047	2.65	.045
JANUARY 10, 1930, SAMPLES								
Orangeburg	3.62	0.06	2.26	0.04	4.21	0.07	2.85	0.05
Norfolk	3.87	.06	2.87	.05	3.88	.07	(3)	(3)
Ruston	3.47	.07	2.41	.04	(3)	(3)	2.24	.04
Kalmia	6.90	.10	3.15	.07	(3)	(3)	(3)	(3)
Average	4.46	.07	2.67	.05	4.05	.07	2.54	.04

[1] Analysis made by ignition method.
[2] For description see soil survey by Smith and Carter (*22*).
[3] No sample taken.

in favor of the burned areas and sometimes in favor of the unburned areas. It is known that the available nitrate nitrogen is taken up rapidly in the early flush of forage growth. A simple calculation from the known yields and analyses of the forage shows that the difference in nitrogen content for different areas, after the growing season had advanced approximately 90 days, may have been sufficient to be reflected in the analyses of the soil.

The soil samples taken January 10, 1930, during the dormant period of plant growth for the region, were repetitions of samples taken April 23, 1929, during the season of flush growth of the native vegetation of the region and after about 3 months of the growing season.

In the soil samples taken in January, the variation in organic matter and nitrogen from burned and unburned areas during the dormant period for plant growth, as shown in table 1, was reasonably constant. The average content of organic matter in all samples from burned areas was 4.32 percent as compared with 2.63 percent for the unburned areas, or a ratio of about 1.6:1. The corresponding average differences in nitrogen content were 0.072 percent and 0.048 percent, or a ratio of 1.5:1. The percentages of organic matter and nitrogen were in all cases higher on the burned areas. The highest percentage of organic matter from any unburned sample did not equal the lowest from any burned sample.

The differences in January between the burned and unburned areas in both organic matter and nitrogen were of such magnitude as to be significant. A difference in weight of 0.01 percent in a moisture-free sample of soil to a depth of 6 inches would amount to approximately 155 pounds per acre, according to the weights of Mississippi soils as given by Logan (*13*). In terms of nitrogen for soils that are deficient in this element, a difference of 0.001 percent, when analysis is made to the third decimal point, is significant. The average difference in percentage of nitrogen was 0.024 percent (0.072−0.048), which represents approximately 400 pounds of nitrogen per acre, in favor of burning. This difference is equal in amount to the nitrogen in an application of approximately 2,400 pounds of nitrate of soda, the common nitrogenous fertilizer of the region.

The conclusion seems warranted that sampling soils for nitrogen during the growing season would give unreliable comparisons for soils that are producing crops varying widely in quantity and quality, especially for soils deficient or low in nitrogen, where the current supply of available nitrogen is a limiting factor for plant growth.

With respect to the soil samples taken at a time of year when plant growth is practically dormant, and over a large area which previously had been subject to uniform treatment, it is reasonable to conclude that the differences in soil analyses were due directly or indirectly to differences in the treatment while under control.

GROWTH OF FORAGE

Throughout the course of the experiment, the growth of forage in the different areas was observed annually on a series of more than 50 rectangular plots of 0.01 acre each.

In 1930, after 8 years of annual burning as compared with complete fire protection over the same period, weights were taken of forage on burned and unburned areas where neither had been grazed (table 2). Two of the 0.01-acre plots were used for each of the two predominating grasses, *Andropogon scoparius* (little bluestem) and *A. tener*, where they were growing in practically pure stands, and two plots for mixed stands. These were selected in the open, away from shade and only a few yards apart on each side of the fire line so that all conditions would be the same except the factor of fire.

TABLE 2.—*Yield per acre*[1] *of the predominating grasses on ungrazed areas, burned and unburned, for 8 years*

Kind of grass	Green plant per acre on—	
	Burned area	Unburned area
	Pounds	*Pounds*
Andropogon scoparius	5,121	3,623
A. tener	6,957	1,206
Mixed stand	5,749	2,415
Average	5,942	2,415

[1] The grasses were clipped about one-half inch above the ground.

The differences in weight on the burned and unburned areas were due chiefly to the reduction of stands (smaller number of plants per acre) on the unburned plot, although there was a reduction in the vigor of growth on this plot as shown by the characteristic spindly growth of plants that are required to grow through a mulch that reduces light in the early stages of growth. The average of the maximum heights of the plants on the plots studied in the burned area was 20 inches. The corresponding figure for the unburned area was 30 inches. From these studies it appeared that the density of the grass growth on areas that were not burned was reduced from year to year by the smothering or mulching effect of the dead debris of the grasses themselves. On unburned areas where the grasses were further blanketed by the "strawfall" from pine saplings, forage growth was almost completely eliminated in the course of a few years. This reduction in forage growth through the action of dead debris on unburned land is cumulative from year to year and is most rapid where the forage is not grazed by cattle.

Laird (*11*), working with five important sod-forming grasses under pasture conditions, found that approximately 50 percent of the dry weight of the plants was in the root system and that most of the weight of the root was in the 8 inches just below the surface of the soil.

On the experimental area 30 species of native legumes,[7] most of which are perennials, occur in considerable abundance. In 1931, after 9 years of burning, counts of the legume plants were made in each of the 0.01-acre plots in the four experimental areas. From these counts the number of legume plants per acre was calculated, as shown in table 3.

TABLE 3.—*Comparison of legume plants on burned and unburned areas*

Treatment of area	Legume plants per acre on—	
	Grazed area	Ungrazed area
	Number	*Number*
Burned annually (9 years)	35,700	41,500
Unburned	27,600	17,600
Difference	8,100	23,900

From tables 2 and 3 it appears that the cumulative smothering effect of unburned plant debris not only reduced the grasses on the protected areas but also reduced the legumes to the extent that after 9 years of fire protection they were less than half as numerous as on the area burned annually over the same period, where neither area had been grazed. These counts confirm observations made in Georgia by Stoddard (*23*) and in Florida by Harper (*9*). In the grazed areas the number of legumes on the protected plots also was materially less though the difference was not so marked.

A strip survey[8] of the forage cover of the entire county in which the experimental area was located showed that the legumes were most abundant on the well-drained soils. This observation confirms those of previous investigators.

The burned and ungrazed area had one more legume plant for approximately each 2 square feet than had the unburned and ungrazed area. The probable effect of this difference in legume population on the quantity of nitrogen gathered from the air is obvious. It is also

[7] The seeds of 20 species found at McNeill, Miss., have been determined by Stoddard (*23*) to be important quail feed.
[8] A sampling process based on studies of representative small plots at regular intervals.

clear that doubling the plant growth per acre would greatly increase the accumulation of organic matter in the soil through decay of plant roots.

CRUDE PROTEIN AND ASH IN FORAGE

It is to be expected that the difference in nitrogen in soils from burned and unburned areas, as shown in table 1, would be reflected somewhat in a difference in crude protein in forage from those areas. The quantity of the protein in plants indicates the fertility of the soil, particularly soil that is deficient in nitrogen. To compare the forage from the burned and unburned areas for content of crude protein, and also for ash, samples of the two predominating species of grasses, *Andropogon scoparius* and *A. tener,* were taken in 1929 and again in 1931 after 7 and 9 years of burning and fire control, respectively. Composite samples were made by cutting and mixing the current growth from a large number of random locations. Samples were taken from April to June during the flush of the early season's growth. Table 4 presents a summary of the results obtained. No sample from the unburned areas equaled the comparable sample from the burned areas.

TABLE 4.—*Comparison of the average crude protein and ash content of moisture-free samples of grasses on burned and unburned areas*

Treatment of area	Crude protein	Ash
	Percent	*Percent*
Burned annually (7 and 9 years)	10.15	7.92
Unburned	7.77	6.86
Difference	2.38	1.06

A difference of 2.38 percent in crude protein is sufficient to affect the feeding value of the forage, and the sale value of commercial feeds is determined largely by the difference in protein content. A difference of 1.06 percent in ash also would affect the value of forage plants as feed (*3, 20*).

MINERAL FERTILIZING ELEMENTS

In 1930, after 8 years of burning and fire control, soil samples representing the four soil types in the burned and unburned areas were analyzed for their content of mineral elements, namely, aluminum oxide, magnesium oxide, calcium oxide, potash, phosphoric acid, and sulphur trioxide. The total quantity of these minerals in the ash was as follows: Burned areas, average of all samples, 2.581 percent; unburned areas, 1.899 percent; difference in favor of burned areas, 0.682 percent. No sample from the unburned areas equaled the comparable sample from the burned areas.

These analyses of the mineral fertilizing elements of the soil substantiate the statements of previous investigators, already presented, that burning does not deplete the mineral fertility of the soil, but returns it directly to the soil where it becomes quickly available for the growth of plants.

SOIL MOISTURE

As a secondary influence of increased organic matter in the soil, it would be expected that soil moisture would increase because of the known water-holding capacity of organic matter in soil.

The region under consideration has a heavy rainfall distributed throughout every month of the year, November having the minimum amount. The average rainfall in November over a 27-year period was 3 inches. Ordinarily there is no deficiency in surface moisture except on steep slopes or light sandy soils, although during periods of drought the soil moisture is rapidly reduced.

The data obtained on soil moisture were based on samples representing different soil types and varying degrees of vegetative growth. Individual samples collected during the growing season accordingly showed considerable variation with no particular trend. In view of the rather wide variation in organic matter for different soil types and the patchy vegetative growth on the unburned pasture, due to spotted grazing, it was realized that the different conditions might give rise to unreliable comparisons unless large numbers of samples were taken. Accordingly more than a thousand individual samples were obtained to make more than 200 composite samples. These represented soil from the surface to a depth of 12 inches for both the burned and unburned areas.

Each of the composite samples was made up of from 5 to 10 individual samples taken within a radius of about 10 feet. No sample was taken less than 24 hours after a rainfall. The results of this investigation are given in table 5.

TABLE 5.—*Average percentage of soil moisture in samples of soil from burned and unburned areas, Apr. 21-Oct. 9, 1931*

Treatment of area	Composite samples	Moisture
	Number	*Percent*
Unburned	124	9.63
Burned	119	9.46
Difference	5	.17

Table 5 shows no significant difference in the moisture content of the burned and unburned areas. However, in considering the moisture data, the wide variation between plant growth on the burned and unburned areas must be taken into account since a ton crop of hay per acre requires the use of about 250 tons of water during the period of its growth (*18*). When the moisture taken from the soil and transpired by a much larger forage production is considered, the conclusion seems warranted that the additional organic matter in the soils on the burned areas must have increased their water-holding capacity to a considerable extent. This is further confirmed by moisture determinations of surface-soil samples taken in May 1930 during the flush of plant growth, and in December after the plant growth was mature. The popular conception is that a mulch of litter on top of the soil conserves moisture at the surface, and the samples which furnished the data shown in table 6 were taken to a depth of 1 inch.

TABLE 6.—*Soil moisture of burned and unburned areas at a depth of 1 inch*

Condition of area	Moisture content of soil [1] on—		Condition of area	Moisture content of soil [1] on—	
	May 21, 1930	Dec. 6, 1930		May 21, 1930	Dec. 6, 1930
Burned:	*Percent*	*Percent*	Unburned:	*Percent*	*Percent*
Grazed	10.3	11.1	Grazed	9.9	9.9
Ungrazed	9.3	14.9	Ungrazed	10.0	13.2

[1] Rainfall for the 30 days ended May 19 was 3.25 inches and for the 30 days ended Dec. 5, 6.37 inches. Of these quantities 2.09 inches fell on May 19 and 0.55 inch on Dec. 5.

Although the burned and ungrazed area produced a forage growth more than double that on the adjacent unburned and ungrazed area, it still maintained its moisture content and ended the growing season with 1.7 percent more moisture.

Merkle and Irvin (*17*) have shown that laboratory results in the conservation of moisture by a mulch, where the soil tubes are in contact with a water table, do not apply in practice to field conditions where no such water table exists near the surface of the soil. In the latter case, the conclusion seems warranted that the maintenance of soil moisture on the burned areas was due to the increased organic matter in the soil, and that the mulch of accumulated debris on the unburned area did not have the effect popularly described.

Water absorbed by plant debris, in place on top of the soil, is subject to the same sharp division from soil moisture that has already been made between organic matter on top of soil and that incorporated with the soil. It is obvious that any water absorbed by the litter is held away from the soil until it is evaporated. It is obvious also that evaporation is more rapid in the presence of free-air circulation than after moisture is absorbed in the soil. However, the water absorbed directly by the surface litter is a very small percentage of the total rainfall. Samples of a 9-year accumulation of three kinds of plant debris were carefully removed from measured areas on the experimental tract and air-dried. The quantity of water they would absorb to the saturation point was then determined by weight and calculated in terms of inches of rainfall. It was found that the maximum quantity, 0.11 inch, was absorbed by pine straw. Oak leaves absorbed 0.09 inch and dead grass 0.05 inch.

A mulch of plant debris in humid areas appears to affect the soil moisture chiefly by suppressing plant growth, which would take up moisture and transpire it through the leaves. The quantity of water absorbed by such litter is so small that it would not influence soil moisture to any appreciable extent, although it might absorb light showers and deprive surface-feeding plants of a temporary supply of moisture that would freshen plant growth in times of dry weather. Such effects on pastures from showers are well known. It has already been shown that accumulated litter did not raise the soil-moisture content even where it has suppressed plant growth about one-half. Any effect popularly ascribed to a leaf litter, in this case did not compensate for the increased soil moisture held in an adjacent soil with a higher organic-matter content, although the adjacent burned-over soil was supporting about twice the plant growth per acre.

SOIL FLORA

The micro-organisms of the soil are known to be greatly increased by the addition of organic matter, since the organic matter furnishes the energy and nitrogen necessary for growth and reproduction. However, counts of soil organisms vary greatly from time to time and are not a reliable index of soil fertility. The following counts are presented merely as being of interest.

The average bacterial count per gram of soil in 1930 was 1,242,000 for the burned and 857,000 for the unburned areas. In only 1 sample out of 11 did the count on an unburned sample exceed that on the corresponding burned sample. The difference in favor of the burned samples was 385,000 organisms per gram of soil. A larger number of bacteria in the burned soil would be expected in view of the greater amount of organic matter and nitrogen there, as shown by previous analyses. Samples also were collected before and after burning, for the same season. Of 5 sets of samples compared in this way, 3 showed decreases in soil organisms after burning and 2 showed increases. The increases were so great on the two samples, however, that the average increase following the fire was 258,000 organisms per gram of soil.

Coleman (*5*) has shown that the activities of soil organisms are greatest at temperatures between 86° and 100° F. The average of nine soil temperatures taken to a depth of 3 inches between March 16, 1924, and April 24, 1924, after a 3-year accumulation of plant debris on the unburned area, was 78° for the burned area and 72.5° for the unburned area, or a difference of 5.5° in favor of the burned area. It should be understood, of course, that the temperatures were not taken on or near the days of actual burning, and that the higher temperature was the nearer to the range of optimum temperatures. The results tend to account for the average higher bacterial counts following burning.

DISCUSSION

Although the soil and topography in southern Mississippi vary some what from those of other locations in the longleaf pine belt, the growth of grasses may be considered in general as typical for the entire area of well-drained lands. In a region more than 1,200 miles in extent, which once grew one species of tree in almost pure stands, it would be expected that factors influencing the growth of associated grasses and legumes on the forest floor would be nearly constant enough to produce in general a rather uniform herbage growth; and this growth is clearly associated with the effects of centuries of periodic grass fires.

To say that burning the organic matter in the form of plant debris on the forest floor or on top of virgin soils tends to increase the organic matter and nitrogen content of the soil may seem paradoxical. Yet it has been shown that the increase of organic matter in the soil is due primarily to the decay of plant roots and that incorporation of plant debris with the soil to form humus is an extremely slow process. It is evident also that any factor that increases the number of plants per acre will of necessity increase the formation of organic matter through the addition of roots to the soil, regardless of what becomes of the tops of the plants. In the experiments described the annual use of winter grass fires approximately doubled the growth of ungrazed grasses and legumes per acre over that produced on similar areas completely protected from fire, and caused a corresponding increase in the soil organic matter to a depth of 6 inches.

The soils considered are relatively heavy soils for the region. On lighter sandy soil, where the vegetative growth is much less dense, the reduction in plant growth through fire protection and the subsequent effect on the soil would necessarily be a much slower process.

It has been pointed out that nitrogen in the soil is derived from the gaseous form in the air, principally through the medium of bacteria associated with legumes, and that there is a constant loss of soil nitrogen which must be replaced if the soil nitrogen is to be held in balance or increased. In these experiments the annual use of winter grass fires maintained a legume growth on an ungrazed burned area about twice that on a similar area protected from fire, and the hypothesis seems entirely warranted that this increased legume population has caused a corresponding increase of nitrogen on the burned areas over that on the unburned areas. The difference shown by soil analyses may be due, however, partly to an increase of nitrogen on the burned areas and partly to a loss of nitrogen by leaching from the unburned soils where the current plant growth has been greatly reduced.

In studies of the effect of burning on mineral fertilizing elements of the soil, there was a marked difference in favor of the burned areas. Data obtained on soil moisture showed no significant differences, in actual moisture content, but the burned areas produced larger yields of plant growth with attendant larger moisture requirements which evidently were supplied. Data on soil micro-organisms indicate that burning tends to increase their number.

SUMMARY

Analyses of soils taken after 8 years of annual grass burning as compared with complete fire protection on rolling longleaf pine land in southern Mississippi showed 1.6 times as much organic matter in the burned-over soils as in the soils protected from fire. The burned-over soils also contained 1.5 times as much nitrogen as the soils protected from fire. The greater quantities of organic matter and nitrogen apparently result chiefly from roots rather than from tops of plants.

Whether plant debris was burned in place on top of the soil, or was left to rot in place on top of the soil, apparently had no direct effect on either the organic-matter content or the nitrogen content of the soil. In both cases, the organic matter and nitrogen aboveground were largely lost to the soil and the nonvolatile mineral fertilizing elements were returned, leaving organic matter and nitrogen increases to be influenced by the amount and composition of decaying plant roots.

Studies of grass and legume growth on the areas for periods of 8 and 9 years, respectively, showed that the quantity of forage growth on the ungrazed burned areas at the end of the period was more than double that on the unburned areas. The additional quantities of plant roots decaying in the soil on the burned areas apparently account for the increase in soil organic matter to a depth of 6 inches.

The increased growth, on the burned areas, of native legumes, their ability to take nitrogen from the air, and the additional growth of other plants which take up soluble forms of nitrogen and prevent leaching, apparently account for the increased amount of soil nitrogen.

The increase in organic matter and nitrogen on the burned areas was reflected in the higher crude-protein content of the principal forage grasses that grew on burned areas as contrasted with the unburned.

Annual burning returned the nonvolatile fertilizing elements to the soil immediately; this was shown in the analyses of both the soil and the forage growth.

The increased organic matter and nitrogen in the burned-over soils was reflected in an increased number of soil micro-organisms.

The accumulation of plant debris on top of the soil did not materially increase the soil moisture in spite of the fact that much greater amounts of water were required to support the extra forage growth on the burned-over soils.

Organic matter on top of the soil absorbs a portion of the rainfall which is thus prevented from reaching the soil for the use of growing plants.

On the forest floor or on virgin soils, that are not to be plowed, a sharp distinction must be made between the value of organic matter in the soil and organic matter in place on top of the soil.

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